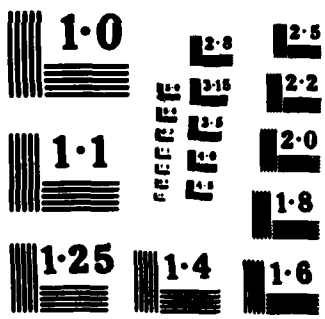
AD A147 525 TRANSPORT PROPERTIES AND DISTRIBUTION FUNCTIONS IN III 1/1
- V SEMICONDUCTORS..(U) WASHINGTON UNIV ST LOUIS MO
DEPT OF ELECTRICAL ENGINEERING B W ABRAHAM-SHRAUNER
UNCLASSIFIED NOV 84 WU/EE 84463-2 N00014-82-K-0692 F/G 9/1 NL


1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·2
2·5
2·8
3·15

# TRANSPORT PROPERTIES AND DISTRIBUTION FUNCTIONS IN III - V SEMICONDUCTORS

B. W. Abraham-Shrauner

Department of Electrical Engineering
Washington University
St. Louis, MO 63130

November, 1984



TECHNICAL REPORT WU/EE-64463-2

Office of Naval Research
Arlington, VA 22217



Contract: N000 14-8 2-K-0692
Contract Authority: NR 243-046

Approved for public release; distribution unlimited.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

## REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION: Unclassified | 1b. RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY | 3. DISTRIBUTION/AVAILABILITY OF REPORT |
| 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S): WU/EE-64463-1 | 5. MONITORING ORGANIZATION REPORT NUMBER(S) |
| 6a. NAME OF PERFORMING ORGANIZATION: Dept. of Electrical Engr. Washington University; 6b. OFFICE SYMBOL (If applicable) | 7a. NAME OF MONITORING ORGANIZATION |
| 6c. ADDRESS (City, State and ZIP Code): St. Louis, MO 63130 | 7b. ADDRESS (City, State and ZIP Code) |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Office of Naval Research; 8b. OFFICE SYMBOL (If applicable) | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N000-14-82-K-0692 |
| 8c. ADDRESS (City, State and ZIP Code): Code 414, 800 North Quincy Street Arlington, VA 22217 | 10. SOURCE OF FUNDING NOS. |

| PROGRAM ELEMENT NO. | PROJECT NO. | TASK NO. | WORK UNIT NO. |
|---|---|---|---|
| 61153N | RR 021 02-03 | NR 243-046 | Same as Task No. |

11. TITLE (Include Security Classification)

12. PERSONAL AUTHOR(S): Barbara Abraham-Shrauner

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Yr., Mo., Day) | 15. PAGE COUNT |
|---|---|---|---|
| Final technical | FROM 9/1/82 TO 5/31/84 | October, 1984 | |

16. SUPPLEMENTARY NOTATION: ONR Scientific Officer (202)696-4218

| 17. COSATI CODES | | |
|---|---|---|
| FIELD | GROUP | SUB. GR. |
| | | |
| | | |

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): III-V semiconductory; drift mobility; ternary semiconductors negative differential resistance; electron distribution functions; diffusion and maximum anisotropy approximation

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Approximate analytical expressions for electron distribution functions in III-V semiconductors have been derived for high and low electric fields. For low electric fields two analytic methods were used and compared with an earlier iteration method and a new perturbation method. All gave similar distribution functions and drift mobility. For high electric fields the electron distribution function was found within the diffusion approximation by an expansion inversely in the electric field. For $Al_{0.25}In_{0.75}$ As the effects of p-wave scattering and nonparabolic energy bands were not found to be the cause of the negative differential resistance. Alloy scattering in ternary semiconductors was treated in the coherent potential approximation. The validity of the diffusion and maximum anisotropy approximation has been assessed by an expansion inversely in the electric field of the polar optical collision term in high electric fields.

| | |
|---|---|
| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS ☐ | 21. ABSTRACT SECURITY CLASSIFICATION: Unclassified |

| 22a. NAME OF RESPONSIBLE INDIVIDUAL | 22b. TELEPHONE NUMBER (Include Area Code) | 22c. OFFICE SYMBOL |
|---|---|---|
| Dr. Max Yoder | (202) 696-4218 | |

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

SECURITY CLASSIFICATION OF THIS PAGE

## I. OBJECTIVES OF RESEARCH

The objective of this research was to derive approximate analytic expressions for electron distribution functions in III-V semiconductors in order to calculate transport properties. The approach was viewed as an alternative to Monte Carlo and drifted Maxwellian calcuations. The use of analytic expressions for the electron distribution function was intended to reduce the cost of numerical calcuations and to facilitate parameter studies of transport coefficients, in particular the temperature dependence of the drift mobility. The objective during the two years of this contract was to focus on the high electric field regime for GaAs, InP and ternary semiconductors such as $Al_{0.25}\ I_{0.75}\ As$. For ternary III-V semiconductors nonparabolic energy bands were to be included in the central valley for polar optical scattering in order to understand the negative differential resistance predicted for electrons in the central valley alone. Alloy scattering was also to be considered. An attempt to include intervalley scattering for GaAs was to be made. All new results were to be compared with previous numerical and experimental results where possible.

## II. SUMMARY OF RESEARCH RESULTS

Several related research topics have been explored. The main thrust of the research has been the development of theoretical methods for calculating electron distribution functions and the drift mobility in III-V semiconductors. The contract has supported in addition to the principal investigator one graduate student, Sik Han Soh, who completed his master's thesis in August, 1984. He is now employed as a project engineer working with III-V semiconductors at Hewlett-Packard in Singapore. His thesis[1] was entitled "Electron Distribution Functions and Mobility in III-V Semiconductor Compounds for High and Low Electric Fields". A paper[2] on part of this work appears in The Physics of Submicron Structures which has been published by Plenum. A second paper is planned on the effect of p-wave scattering and nonparabolic energy bands on the negative differential resistance arising in the central valley of the conduction band for certain ternary III-V semiconductors. Also a short collaboration

with Professor Peter Fedders of the Physics Department at Washington University and Professor Charles Myles of the Physics Department at Texas Tech University on the coherent potential approximation applied to alloy scattering in ternary III-V semiconductors resulted in a talk[3]. For comparable percentages of disorder the scattering due to off-diagonal disorder was found to dominate in alloy scattering in a two-band model for III-V semiconductors. This project was not pursued further by the principal investigator because a subsequent paper by Professors Dan Rode and Peter Fedders[4] showed that for most ternary III-V semiconductors of interest in device applications the Born approximation could be justified such that the coherent potential approximation is not really needed. A resolution of some of the differences in the diffusion approximation[5] and the maximum anisotropy approximation[6,7] used to simplify the electron distribution function at high d.c. electric fields has been made by means of an asymptotic expansion inversely in the electric field of the steady-state Boltzmann equation for polar optical scattering. A better understanding of the applicability of these approximations is now feasible[8]. Preliminary calculations on the extension of the calculation of the electron distribution function by approximate analytic expressions for intervalley scattering was begun. That effort was not continued because of an uncertainty in the basis of the validity of the diffusion and maximum anisotropy approximations and because the principal investigator ran out of time in one year. The drift mobility for InP was calculated but not investigated further as the time-of-flight data was not available.

The master's thesis of Mr. Soh included several methods for determining electron distribution functions in low electric fields and the calculation of the electron drift mobility for polar optical scattering. The methods were: iteration[9], perturbation, and two analytic methods. The iteration method was calculated numerically and compared with previous numerical results that had been compared with experimental data. The perturbation method was numerical but the two analytic

methods produced approximate analytic expressions for the electron distribution function from which the drift mobility was calculated. The results from all methods were similar. For high electric fields the expansion of the steady-state Boltzmann equation inversely in the electric field within the diffusion approximation for the electron distribution function was reviewed[2]. The electron distribution function was compared with that derived by Stratton[10] for parabolic energy boards and agreement found for an expansion in 1/E of his result. Neither distribution function is normalizable and intervalley scattering needs to be included for GaAs; for certain ternary III-V semiconductors intervalley scattering may be omitted in a certain range. For high electric fields p-wave scattering and nonparabolic energy bands were included in the polar optical scattering term. For GaAs and even $Al_{0.25}$ $In_{0.75}$ As the effects of p-wave scattering and nonparabolic energy bands were not found to alter the electron distribution significantly. Consequently the negative differential resistance for ternary III-V semiconductors does not appear to be caused by the nonparabolic character of the central valley of the conduction band. Another supporting argument for our conclusion can be found in the Monte Carlo calculations[11] of the electron drift velocity-electric field curve where p-wave scattering is negligible. As Rode[12] has pointed out nonparabolic energy bands exist only if there are p-wave matrix elements as well as s-wave matrix elements. Hence, one cannot invoke nonparabolic energy bonds at the same time p-wave scattering is dropped.

To compare the diffusion and maximum anisotropy approximations an expansion inversely in the electric field has been made of the steady-state Boltzmann equation for a d.c. electric field and polar optical scattering. This model is expected to be reasonable for ternary semiconductors if alloy scattering is added; for GaAs intervalley scattering should be added. For $E_o/E$ small where $E_o$[13] is the critical electric field characterized by the strength of the coupling to the polar modes, the symmetric part of the distribution function for electrons in the central valley is a constant. The asymmetric part of the electron distribution function can be

represented as an expansion in odd order Legendre polynomials whose argument is the cosine of the angle between the electric field and wave vector. The coefficients of the odd order Legendre polynomials for high electric fields and electron energies high compared to an optical phonon energy obey a modified maximum anisotropy relation where no even order coefficients for $n > 0$ exist. The diffusion approximation does not give the entire electron distribution function correctly but for high electric fields it produces a functional from which the electron density and drift velocity for electrons in the central valley can be correctly calculated for polar optical scattering.

References


1. S. H. Soh, Master's Thesis, "Electron Distribution Functions and Mobility in III-V Semiconductor Compounds for High and Low Electric Fields", Washington University in St. Louis, August, 1984.

2. B. Abraham-Shrauner and S. H. Soh, "Electron Distribution Functions in GaAs for HIgh and Low Electric Fields", paper presented at the Workshop on the Physics of Submission Structures, Urbana, Illinois, June (1982), in The Physics of Submission Structures, Plenum Press, New York (1984).

3. P. A. Fedders, B. Abraham-Shrauner and C. W. Myles, "Diagonal and Off-Diagonal Disorder Contributions to Alloy Scattering in the CPA", Bull. Am. Phys. Soc., March (1983).

4. D. L. Rode and P. A. Fedders, "Electron Scattering in Semiconductor Alloys", J. Appl. Phys. 54, 6425 (1983).

5. E. M. Conwell and M. O. Vassell, Phys. Rev. 166, 797 (1968).

6. G. Baraff, Phys. Rev. 133, A26 (1964).

7. L. Stenflo, Proc. IEEE 55, 1088 (1967).

8. B. Abraham-Shrauner, "The Diffusion and Maximum Anisotropy Approximation for Polar Optical Scattering", (preprint) (1984).

9. A. Fortini, D. Diguet and J. Lugard, J. Appl. Phys. 41, 3121 (1970).

10. R. Stratton, Proc. Royal Soc. A246, 406 (1958).

11. J. R. Hauser, T. H. Glisson and M. A. Littlejohn, Solid-State Electronics, 22, 487 (1979).

12. D. L. Rode, "Low-Field Electron Transport" in Semiconductors and Semimetals, R. K. Willardson and A. P. Beer, ed. 10, Academic Press, New York (1975).

13. E. M. Conwell, High Field Transport in Semiconductor, Academic Press, New York (1967).

## PERSONNEL

Principal Investigator - Barbara Abraham-Shrauner
Graduate Student - Sik Han Soh

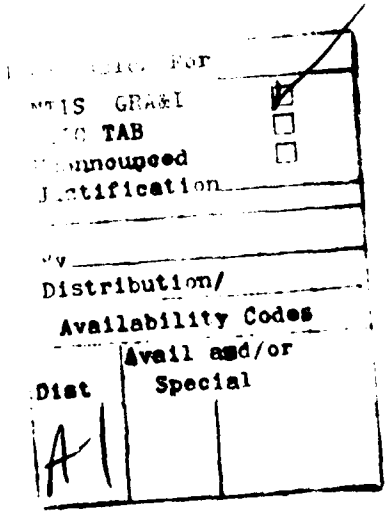
## PUBLICATIONS AND TALKS

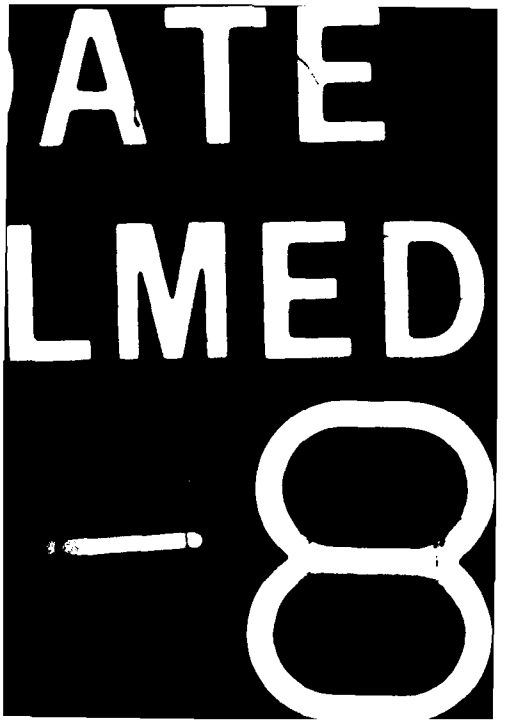
S. H. Soh, Master's Thesis, "Electron Distribution Functions and Mobility in III-V Semiconductor Compounds for High and Low Electric Fields", Washington University in St. Louis, August, 1984.

B. Abraham-Shrauner and S. H. Soh, "Electron Distribution Function in GaAs for High and Low Electric Fields", paper presented at the Workshop on the Physics of Submission Structures, Urbana, Illinois, June (1982), in The Physics of Submission Structures, Plenum Press, New York (1984).

P. A. Fedders, B. Abraham-Shrauner and C. W. Myles, "Diagonal and Off-Diagonal Disorder Contributions to Alloy Scattering in the CPA", Bull. Am. Phys. Soc., March (1983).

B. Abraham-Shrauner, "The Diffusion and Maximum Anisotropy Approximation for Polar Optical Scattering" (preprint) (1984).




ATE
LMED
8